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Meditation and attention: A controlled study on long-term meditators in behavioral performance and event-related potentials of attentional control

Han-Gue Jo [a], Stefan Schmidt [a,b,*], Elisa Inacker [a], Michael Markowiak [a], Thilo Hinterberger [c]

[a] Department of Psychosomatic Medicine, Medical Center - University of Freiburg, Germany
[b] Institute of Transcultural Health Studies, European University Viadrina, Frankfurt (Oder), Germany
[c] Department of Psychosomatic Medicine, University Medical Center Regensburg, Germany

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A B S T R A C T

Meditation practice involves attention regulation, and thus is thought to facilitate attention control mechanisms. Studies on meditation techniques using a behavioral measurement of the Attention Network Test (ANT) have shown enhanced attention control, but neural features remain unknown. In the present study, event-related potentials (ERPs) and behavioral data from twenty long-term meditators were examined, compared to data obtained from twenty matched controls. Results showed that meditators made fewer error responses than controls, especially during the incongruent target condition, suggesting higher accuracy in executive attention control among meditators. The P3 amplitude in the parietal area remained constant in the congruent and incongruent target conditions among meditators, indicating a higher parietal P3 amplitude during the incongruent target condition relative to matched controls. The findings that meditators exhibited fewer error responses on the ANT and a lack of parietal P3 modulation irrespective of reaction time are discussed in the context of attentional resource allocation.

1. Introduction

Meditation can be described as a self-regulation technique that focuses on the way of paying attention (Davidson and Goleman, 1977; Shapiro, 1982; Schmidt, 2014). Mindfulness meditation as a specific form of meditation targets a mental state of non-judgmental awareness in the present moment (e.g. Kabat-Zinn, 2005). Therefore, it can be expected that individuals who meditate on a regular basis have enhanced their attentional system and thus show improved performance on a task that assesses attention-related capacities. Attention, however, is a broad concept and its various aspects should be considered separately. In the research at hand, we use the attention model of Posner and Petersen (1990) who described three components (networks) of the attention system which are functionally and anatomically distinct from other neuronal systems: 1) an *alerting* network controlling the state of alertness and vigilance, 2) an *orienting* network organizing the goal-oriented focusing of attention, and 3) an *executive* network controlling the response execution (Fan and Posner, 2004). Growing evidence has shown the effects of meditation practice on attention and attention control (Chiesa et al., 2011; MacLean et al., 2010). For instance, Chan and Woollacott (2007) studied the long-term effects of meditation on specific attention control tasks, namely a stroop task that is known to measure executive attention (i.e. the inhibition of prepotent or incorrect responses) and a global–local letter task that tests orienting attention (i.e. the orientation to specific objects in the attentional field). Comparing meditators to non-meditators, the results suggested that long-term meditation practice increases the efficiency of executive attention (see also Teper and Inzlicht, 2013) but shows no effect on orienting attention. Along the same line, enhanced executive attention in experienced meditators, relative to novices, has also been found using an Attention Network Test (ANT) paradigm (Jha et al., 2007). In addition, an integrative short-term meditation program (IBMT, integrative body-mind training) involving five days of twenty-minutes training in group sessions was enough to improve executive attention as measured by the ANT (Tang et al., 2007).

The Attention Network Test (ANT, Fan et al., 2002; see Fig. 1) is a widely used computerized task that comprises cued detection (i.e. tasks involving different types of warning cues in advance) and a flanker-type paradigm (congruent and incongruent target stimuli). The task requires participants to indicate the direction of a central target arrow as fast and as accurately as possible by pressing either a left or a right button. The ANT assesses three independent aspects of attention. These, in turn, are associated with the aforementioned three different networks, namely the alerting, orienting, and executive network. The alerting network is associated with achieving and maintaining a vigilant or alert state, which is examined through comparing trials with and

* Corresponding author at: Department of Psychosomatic Medicine and Psychotherapy, University Medical Center Freiburg, Hauptstraße 8, 79104 Freiburg, Germany.
E-mail address: stefan.schmidt@uniklinik-freiburg.de (S. Schmidt).

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Table 1
The number of trials analyzed for each condition.

Condition	No cue	Center cue	Spatial cue	Congruent	Incongruent
Controls (n = 20)	84.3 ± 11.30 (56–96)	85.4 ± 11.66 (51–96)	87.65 ± 10.28 (57–96)	131.15 ± 14.74 (76–143)	126.2 ± 17.61 (88–144)
Meditators (n = 20)	85.9 ± 12.63 (46–96)	85.75 ± 13.17 (46–96)	87.2 ± 11.67 (52–95)	129.95 ± 19.63 (75–143)	128.9 ± 17.74 (69–144)

All the values are given in mean ± SD. The range of the number of trials is shown in parentheses. No significant difference in the number of trials between groups was found for all conditions (all $p > .67$).

without warning cues prior to the target stimulus. The orienting network is responsible for selecting information from sensory input and the orientation toward sensory events. It is examined through presenting respondents with warning cues with and without spatial information regarding the subsequently presented target stimulus. The executive network is related to more complex tasks such as monitoring or resolving conflicts among responses. This network is examined through presenting the target stimulus surrounded by either congruent or incongruent flankers. In addition to the analysis of behavioral data, the combination of the ANT with the multichannel recording of an electroencephalogram (EEG) can reveal important information regarding attentional processing through the analysis of the event-related potentials (ERPs).

Previous studies (Fan et al., 2007; Neuhaus et al., 2010b) have found that the ANT results in individual brain activity across various stimulus conditions as indicated by neurophysiological measures such as ERPs. ERP components of the ANT have been studied in children and adults not only in healthy populations but also in clinically impaired patients with attentional processing disorders such as schizophrenia, attention-deficit/hyperactive disorder (ADHD), multiple sclerosis, or psychopathic syndrome (Kratz et al., 2011; Neuhaus et al., 2007, 2010a, 2011; Racer et al., 2011; Vázquez-Marrufo et al., 2014; Wangler et al., 2011). Two prominent ERP components (i.e. N1 and P3) of the ANT in which amplitudes are modulated either by cueing or by the target stimuli have been reported (Neuhaus et al., 2010b). In healthy adults, parietal P3 following congruent target stimuli showed relatively higher amplitude compared to incongruent target stimuli, while frontal P3 showed an opposite modulation. This pattern of P3 modulations was absent in schizophrenic patients, suggesting a specific deficit in target processing (Neuhaus et al., 2007, 2010a). Other studies with ADHD and multiple sclerosis patients found decreased P3 amplitudes in both the congruent and incongruent condition (Kratz et al., 2011; Vázquez-Marrufo et al., 2014). These results suggest that P3 modulation in the ANT reflects specific brain functions of the target classification that in turn indicate individual capacities of attentional control (Polich, 2007). Another ERP component of the ANT is the N1 recorded over the parietal-occipital region, whose amplitude is modulated by cueing conditions (Neuhaus et al., 2010b). Reduced N1 amplitudes following cue and target stimuli were related to longer reaction times and higher error rates in schizophrenic participants (Neuhaus et al., 2011), suggesting that the N1 amplitude can be used as an index for abnormal visual attention control.

However, despite the growing number of ANT studies that explore meditation techniques (Ainsworth et al., 2013; Elliott et al., 2014; Jha et al., 2007; Tang et al., 2007, 2015; van den Hurk et al., 2010) and a remarkable use of the ANT paradigm in investigating neural features among clinically impaired patients, we are not aware of any report on the neural features of the ANT among meditators. In the present study, we thus aimed to extend the current discussion of the underlying neural mechanism of attentional control through conducting an ANT in combination with 64 channel EEG recordings with experienced meditators.

Many studies have investigated enhanced attentional engagement and the changes of neural activities in experienced meditators (for an overview, see Cahn and Polich, 2006). Using the Oddball paradigm after meditation practice, an increased P3 amplitude following target stimuli was found in both novices (Sarang and Telles, 2006) and

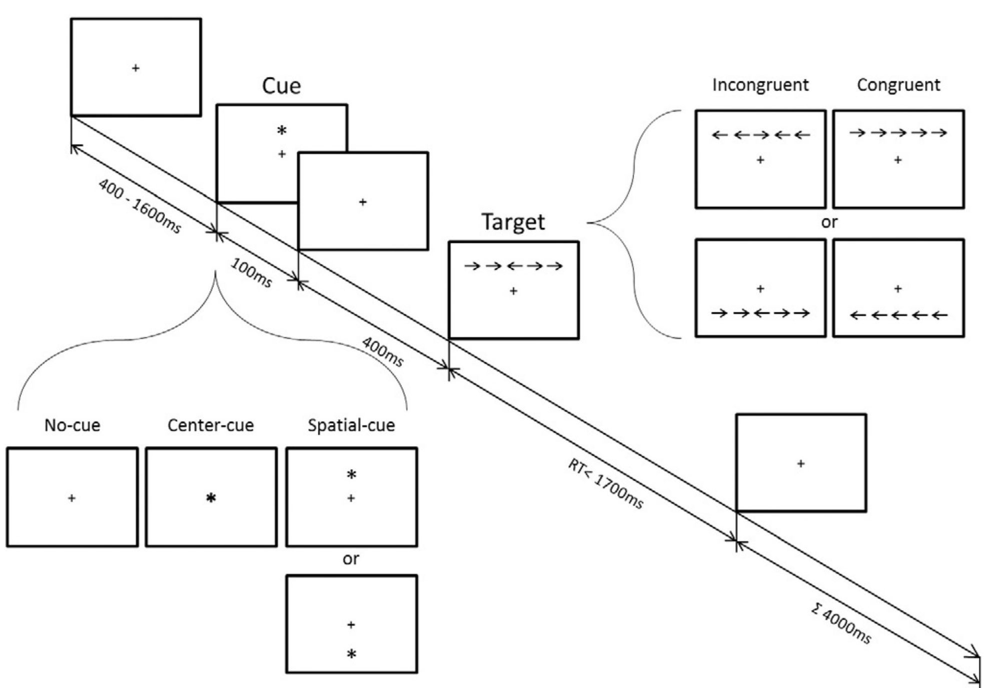

Fig. 1. Schematic time frame of the Attention Network Test.